
CLASSIFICATION AND PROPERTIES OF DURICRUSTS FOR EXCAVATION PURPOSE

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Abstract: Although certain characteristics of duricrusts display a strong resemblance to clastic sedimentary rocks, in terms of lithology, they cannot be classified as rock. These ambiguities on classification may lead to several problems associated with excavation of duricrusts, particularly with regard to method used and rate of payment. In an attempt to draw some guidelines in evaluating the degree of excavatability of duricrusts, this paper highlights some of the fundamental differences and similarities between duricrusts and clastic sedimentary rocks. Laboratory and field data show that, in terms of texture and strength, duricrusts exhibit strong similarities to clastic sedimentary rocks. However, the origin of duricrusts does not fulfill the criteria for classification as rock. As such, for certain geologic materials, lithologic classification alone may not be sufficient to reflect their excavatability. Further verification on the material properties is also an essential aspect to be considered.

Keywords: *Duricrusts; Sedimentary Rocks; Mode of Occurrence; Rock Texture*

Abstrak: Walaupun bahan kerak tanah memperlihatkan beberapa sifat yang hampir sama dengan batuan sedimen klastik, tetapi dari aspek lithologi bahan ini tidak boleh diklasifikasikan sebagai batuan. Ketidakpastian mengenai pengelasan bahan ini boleh menimbulkan beberapa masalah dalam kerja pengorekan kerak tanah terutamanya mengenai kaedah pengorekan dan kadar pembayaran. Dalam usaha mengujudkan prosedur menentukan tahap kebolehkorekan kerak tanah, kertas kerja ini memperjelaskan beberapa perbezaan dan persamaan asas antara kerak tanah dan batuan sedimen klastik. Data ujikaji makmal dan kerja lapangan menunjukkan bahawa dari segi tektur dan kekuatan, kerak tanah menunjukkan persamaan dengan batuan sedimen. Walaubagaimanapun, mod pembentukannya tidak memenuhi kriteria untuk dikelaskan sebagai batuan. Dengan ini bagi bahan-bahan geologi tertentu, pengelasan lithologi sahaja tidak dapat menggambarkan kebolehkorekannya. Penilaian tambahan ke atas sifat-sifat bahan juga merupakan aspek penting yang perlu diambil kira.

Katakunci: *Kerak tanah; Batuan Sediment; Mod Pembentukan; Tekstur Batuan*

1.0 Introduction

Formation of duricrusts is associated with the indurated (strongly cemented) zones in thick weathering profiles and is principally related to the process of deep chemical weathering (Fauiran and Jeje, 1983) hence, duricrusts are widely developed in humid tropical regions. They are resistant to weathering, thus playing a significant role in landscape development of an area. The formation of duricrusts in the zones of weathering profiles implies that they are formed *in situ*, i.e. at location where parent rocks are being disintegrated and decomposed to residual soils.

The strength and hardness of duricrusts are the result of cementation of the loose sediments by cementing materials and therefore, the chemical compositions of the cementing materials dictate the name and classification of duricrusts (see Mohd For Mohd Amin et al., 2005). Iron- and aluminium-rich duricrusts are known respectively, as *ferricrete* and *alcrete*; siliceous duricrusts, or *silcrete*, are the stronger ones among the duricrusts. *Bauxites* and *laterites* are, however, relatively weak materials and therefore, the terms *ferricrete* and *alcrete* are reserved for the indurated forms.

Due to the resistant and strength exhibited by duricrusts, in the field they may occur as *caprocks* and form vertical slopes of several metres height (Mohd For Mohd Amin et al., 2005), modes of occurrence that are only possible for strong geological materials such as rocks. However, there are a number of geological criteria that do not permit duricrusts to be classified as rocks. This situation may lead to problems in classifying and defining the duricrusts (i.e. either as soils or rocks) in excavation work and subsequently, for the associated parties to agree upon the appropriate method of excavation of these materials (see Fauzilah Ismail, 2002). Due to the lack of understanding on the classification and properties of these indurated sediments, the associated earthworks at these sites have been subjected to costly variation order and lengthy arbitration disputes between the contractors and project owners.

Excavatability assessments (based on material properties) by Jerry Chua Kuo Seng (2004) and Fauzilah Ismail (2002), show that duricrusts require mechanical methods to be broken up before removal. Field observations indicate that apart from minor laminations and fractures, duricrusts do not display major weakness planes thus, in terms of mass they can be considered as massive. Excavation work on duricrust observed in Pasir Gudang indicates that ripping (Caterpillar D8) is an effective method for its excavation. However, there are several characteristics of duricrusts that need further verifications before one can conclude that ripping is the best option.

Table 1: Classification of sedimentary rocks (after Waltham 2002)

Clastic sedimentary rocks	Non-clastic sedimentary rocks
<p>RUDACEOUS: coarse grained Conglomerate – rounded fragments. Grain size > 2 mm. Breccia – angular fragments.</p> <p>ARENACEOUS: medium grained between 0.06 – 2 mm. Sandstone & allied rocks.</p> <p>ARGILLACEOUS: fine grained < 0.06 mm Siltstone – quartz particles Shales, clays, mudstone & allied rock</p>	<p>CARBONATES (Organic) Limestone & allied rocks.</p> <p>NON-CARBONATES (chemical) Flint & chert. Coal & lignite. Ironstone. Salt & gypsum</p>

The sedimentary rocks that are comparable to duricrusts include *shales*, *mudrocks*, *siltstones* and *sandstones*. These rocks are also termed as ‘clastic sedimentary rocks’ and their classification are shown in Table 1. They are formed by sedimentation of *transported sediments* such as clay, silt and sand in depositional environments (e.g. coastal areas and ocean basins) that can be several thousands kilometers away from the source of the sediments. For these loose sediments to become sedimentary rocks, they have to undergo *lithification* processes (Waltham, 2002) which include the followings:

- **Cementation** by *cement matrix* like siliceous (silica), ferruginous (iron oxides), calcareous (clacite) and clay.
- **Recrystallisation**, a small scale solution and deposition of minerals.
- **Compaction**, restructuring and change of grain packing with decreasing volume, this is normally associated with high overburden stress (i.e. thick layer of sediments).

In terms of texture and mineralogy, majority of clastic sedimentary rocks essentially consist of quartz, mica, feldspars and clays, set in the cement matrix. The transported sediments that formed clastic sedimentary include *residual soils* that originate from uppermost zone (Zone 6) in weathering profiles. This is also the zone where duricrusts are formed. Depending on the type of the *in situ* rock and climate, these zones may reach a thickness of more than 25 m (Dearman 1974; Saunders and Fookes, 1970).

Lithologic classification such as *soil* and *rock* are terms commonly used to define degree of excavatability of materials in the field. As pointed out in this paper, the lithologic classification alone is not sufficient to indicate the excavatability of certain types of geologic materials. This paper discusses some of the differences and similarities between duricrusts (cemented sediments) and their close counterpart, sedimentary rocks. Lithologic classification implies that duricrusts are not rock materials but their material properties and strengths strongly indicate that they exhibit certain degree of resistance against fracturing.

2.0 Methodology

In an attempt to clarify certain aspects on the excavatability of duricrusts, field and laboratory investigations were conducted on this geologic material. The study was conducted in Dengkil, Selangor and Pasir Gudang, Johor. Field assessments undertaken include observation on mode of occurrence and presence of structural discontinuities. Samples of duricrusts were also collected for further laboratory verification on their material properties and strengths. For lithologic classification, data collected from field observations on duricrusts were compared with that of clastic sedimentary rocks. Data derived from the laboratory tests on the duricrusts were compared with the corresponding properties of sedimentary rocks. For this particular purpose, the typical properties of the sedimentary rocks are listed in Tables A1 to A6 in the Appendix, extracted from various established data.

3.0 Result and Discussion

From the data collected, the differences and similarities between duricrusts and clastic sedimentary rocks, in terms of mode of formation and material properties, are verified.

3.1 Mode of formation and classification

Compared with the mode of formation of clastic sedimentary rock, there are a number of factors that defy duricrusts to be classified as rock:

- Duricrusts are formed within zones of weathering profiles therefore, sediments that form duricrusts are residual (*in situ*) soils that are not being transported and deposited as in the case of transported sediments that form clastic sedimentary rocks.
- Although the formation of duricrusts and clastic sedimentary rock are associated with cementation process, the cementation process of duricrusts takes place *in situ*, at locations where parent rocks are being weathered to residual soils.
- The thickness of overburden of a weathering profile is relatively thinner (10 to 20 m) compared to the thickness of sediments in depositional environments (may reach several 100's m). Consequently, induration process of duricrusts is not associated with compaction and consolidation, which require very high overburden stress.
- Unlike clastic sedimentary rocks, the formation of duricrusts is related to specific climatic regimes.

Lithification process of clastic sedimentary rocks takes place in depositional environments where thick sediments are buried beneath subsequent layers. Cementation and compaction are in a much larger scale hence; sizes of sedimentary rocks being

formed are larger and thicker. Duricrusts usually occur as isolated bodies and as capping and therefore, less extensive in terms of size as compared to sedimentary rocks.

3.2 *Material texture*

Despite the differences in mode of formation, the material texture of duricrusts exhibits strong resemblance to clastic sedimentary rocks i.e. granular texture with mineral grains imbedded in cement matrix. The typical texture of both sandstone and duricrusts is shown in Figure 1.0.



(a) Sandstone



(b) Duricrust

Figure 1: Material texture of sandstone and duricrust

For granular texture, the strength is mainly controlled by the strength of the individual mineral grain (quartz feldspar and mica) and the cement matrix (siliceous, ferruginous and calcareous). When materials with granular texture are subjected to loading, fracturing and initiation of cracks usually commence at the boundary between the mineral grains and the cement matrix. For a weaker cement matrix, fractures may initiate within the cementing material itself. Therefore, the strength and hardness of duricrusts and clastic sedimentary rocks depend on the strength of the cement matrix and its bonding with the mineral grains. Following this, it is thought that the range of strength of duricrusts would be similar to clastic sedimentary rocks.

3.3 *Material properties*

The typical properties of duricrusts obtained from the laboratory tests on collected samples are listed in Table 2. As shown later, these properties of duricrust, are comparable to some sedimentary rocks.

Table 2: Properties of duricrusts obtained Selangor and Johor

Material Properties		Sample from Dengkil, Selangor (Ds)		Sample from Pasir Gudang, Johor (Dj)	
		Min. value	Max. value	Min. value	Max. value
Density	ρ , (kg/m ³)	2230	2571	2127	2551
Compressive Strength based on Rebound No.	q_u , (MPa)	31.7	77.2	20.9	95.8
Slake Durability Index	I_{d1} , % I_{d2} , %	88.31 80.32	93.98 90.50	78.42 71.32	96.46 85.10
Point Load Index	$I_s(50)$, (MPa) UCS, (MPa)	0.41 8.2	2.93 58.6	0.53 10.6	1.96 39.2
Tensile Strength	TS, (MPa)	6.1	7.8	2.5	3.5
Uniaxial Compressive Strength	UCS, (MPa)	42.8	54.4	23.19	36.75
Seismic Velocity	V_p , (m/s)	1630	2650	1690	2800

Note: All tests are conducted according to ISRM (1981)

Due to the similarities in terms of texture and mineralogy, it is reasonable to compare the material properties of these geological materials, specifically on strengths like rebound number (surface hardness), point-load index strength, uniaxial compressive and tensile strength. Physical characteristics like density and seismic (P-wave) velocity reflect the degree of compactness of both materials. In fact these strength and physical properties are the parameters commonly used in assessing the degree of rippability of rock materials (e.g. Pettifer and Fookes, 2004).

Data used in this comparison are those listed in Table 2 where *Ds* and *Dj* are the prefix used for duricrusts collected from Selangor and Johor, respectively. The classification and properties for the clastic sedimentary rocks are listed in Table A1 to A6 in the Appendix. For each property being compared the following can be deduced:

- Density: The *Ds* values range from 2230 to 2571 kg/m³ and for *Dj* is between 2127 – 2551 kg/m³. Comparing these values with sandstone and shale in Table A3, indicates that duricrusts exhibit similar range of density as the clastic sedimentary rocks.
- Compressive strength based on Rebound Number: The *Ds* values range from 31.7 to 77.2 MPa and for *Dj* from 20.9 to 95.8 MPa. Comparing these values with those of clastic sedimentary rocks in Table A1, the range falls within the range of clastic sedimentary rocks. Table A6 classifies this range of value as

Moderately Strong to Strong Rock and typical of some strong cemented sandstone.

- Slake durability index, after first cycle I_{d1} : The D_s values range from 88.3 to 93.9 % and for D_j from 78.4 to 96.5 %. Comparing these values with those in Table A4, shows that duricrusts are classified as Medium to Medium High Durability. This is also typical of clastic sedimentary rocks of moderate strength (ISRM, 1981).
- Point load index I_s (50): The D_s values range from 0.41 to 2.93 MPa and for D_j from 0.53 to 1.96 MPa. Referring to Table A1 this range of value falls within the property of clastic sedimentary rocks. Table A5 classifies this range of I_s value as Moderately Weak to Strong Rock that includes some sedimentary rock and strong cemented sandstone (see Table A6).
- Tensile strength: The D_s values range from 6.1 to 7.8 MPa and for D_j from 2.5 to 3.5 MPa. Referring to Table A1, this range of value falls within the property of clastic sedimentary rocks.
- Uniaxial compressive strength, UCS: The D_s values range from 42.8 to 54.4 MPa and for D_j from 23.19 to 36.75 MPa. Comparing these values with those of clastic sedimentary rocks in Table A1, they fall within that of clastic sedimentary rocks. Table A6 classifies this range of value as Moderately Strong to Strong Rock and it is typical of some strong cemented sandstone.
- Seismic (P-wave) velocity: The D_s values range from 1600 to 2650 m/s and for D_j from 1690 to 2800 m/s. Based on Table A2, this range of velocity is also exhibited by medium to moderately hard shales and sandstones. It is also indicated in Table A2 that *hardpan* (a type of duricrusts) is classified under the same group as clastic sedimentary rocks.

Table 3 lists the resulting comparison, and the remarks noted in the last column summarise the similarity between duricrusts and clastic sedimentary rocks.

4.0 Conclusions

Based on the comparison in terms of lithologic classification and the laboratory assessments on the material properties, a number of conclusions can be made with regard to the geologic materials being studied:

- i. Duricrusts are indurated (strongly cemented) sediments and their formation is related to chemical weathering in thick weathering profiles, as such in terms of lithology, duricrusts cannot be classified as rocks.
- ii. The material texture and minerals composition of duricrusts are similar to clastic sedimentary rocks, therefore their physical properties and strength are comparable to these sedimentary rocks particularly, shale and sandstone. Based

on their material properties, the degree of excavability of duricrusts are thought to be comparable to the sedimentary rocks.

- iii. For excavation purpose, the classification of materials in terms of *soils* and *rocks* is not sufficient to cover wide variety of geological materials. Some may exhibit high strength but do not lend themselves to be classified as rock. Under this situation, *material properties* may be used to indicate the degree of excavability the material.

Table 3: Summary of test results for duricrusts from Selangor (Ds) and Johor (Dj)

Material Properties		Sample from Dengkil, Selangor (Ds)		Sample from Pasir Gudang, Johor (Dj)		*Data from references	Remarks
		Minimum Value	Maximum Value	Minimum Value	Maximum Value	Range	
Density	ρ , (kg/m ³)	2230	2571	2127	2551	2060 - 2700	Similar to shale & sandstone (Table A3)
Compressive Strength based on Rebound Number	q_u , (MPa)	31.7	77.2	20.9	95.8	10 - 200	Moderately strong to strong rocks, similar to some strongly cemented sandstones with silica cement (Table A1, A4 and A7)
Slake Durability Index	I_{d1} , %	88.31	93.98	78.42	96.46	-	Classified as medium to medium high durability material and similar to moderate strength rocks (Table A5).
	I_{d2} , %	80.32	90.50	71.32	85.10	-	
Point Load Index	$I_s(50)$, (MPa)	0.41	2.93	0.53	1.96	0.1 - 10	Similar to moderately weak to strong rocks including sedimentary rocks (Table A1 & A6).
	UCS, (MPa)	8.2	58.6	10.6	39.2	12 - 100	
Tensile Strength	TS, (MPa)	6.1	7.8	2.5	3.5	2 - 20	Similar to elastic sedimentary rocks (Table A1 and A4)
Uniaxial Compressive Strength (UCS)	UCS, (MPa)	42.8	54.4	23.19	36.75	10 - 200	Moderately strong to strong rocks, similar to some strongly cemented sandstones with silica cement (Table A1, A4 and A7).
Seismic Velocity	V_p , (m/s)	1630	2650	1690	2800	1460 - 3660	Hardpan, medium to moderately hard shales and sandstones (Table A2)

* Note: Data from Table A1 through Table A6

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Appendices

Table A1: Typical static mechanical properties of some common rock types (modified from Bengt Stillborg, 1986)

Rock class	Rock type	Unconfined compress. strength σ_c [MPa]	Tensile Strength σ_t [MPa]	Point load Index, $I_{s(50)}$ [MPa]
Sedimentary rock	Limestone	50 - 200	5 - 20	0.5 - 7
	Mudstone	5 - 15	—	0.1 - 6
	Sandstone	50 - 150	5 - 15	0.2 - 7
	Siltstone	5 - 200	2 - 20	6 - 10
	Shale	50 - 100	2 - 10	—

Table A2: Relative seismic (P-wave) velocity (modified after Bickel & Kuesel, 1982)

Type Of Rocks	P-wave velocity m/s
Dry, loose topsoils and silts.	180-370
Dry, heavy, gravely clay; moist, heavy clays; cobbly materials with considerable sands and fines; soft shales; soft or weak sandstones	910-1460
Compacted, moist clays; saturated sands and gravels; soils below water table; dry medium shales, moderately soft sandstones, weathered, moist shales and schists.	1460-1830
Hardpan ; cemented gravels; hard clay; boulder till; compact, cobbly and bouldery materials; medium to moderately hard shales and sandstones , partially decomposed granites, jointed and fractured hard rocks.	1680-2440
Hard shales and sandstones, interbedded shales and sandstones , slightly fractured hardrocks.	2440-3660

Table A3: Density of Rocks (modified after Daly *et al.*, 1966)

Type of sedimentary rocks	Range of Density kg/m ³
Sandstone	2170 – 2700
Limestone	2370 – 2750
Dolomite	2750 – 2800
Chalk	2230
Marble	2750
Shale	2060 – 2660
Sand	1920 – 1930

Table A4: Slake Durability Classification (Gamble, 1971)

Group name and description	% retained after one 10 min. cycle, Id_1 (dry weight basis)	% retained after two 10 min. cycle, Id_2 (dry weight basis)
Very high durability	>99	>98
High durability	98-99	95-98
Medium High durability	95-98	85-95
Medium durability	85-95	60-85
Low durability	60-85	30-60
Very Low durability	<60	<30

Table A5: Classification based on point load index strength (after Broch and Franklin, 1972)

Strength Classification	Is (MN/m ²)	Equivalent UCS (MN/m ²)
Very strong	>6.7	>100
Strong	3.35-6.7	50-100
Moderately strong	0.85-3.35	12.5-50
Moderately weak	0.4-0.85	5-12.5
Weak	0.12-0.4	1.25-5
Very weak rock or hard soil	0.05-0.12	0.6-1.25

Table A6: Classification of rock types based on unconfined compressive strength (after McLean & Gribble, 1980)

Descriptive terms	UCS (MPa)	Rock types
Very weak rock.	< 1.25	Some weakly compacted sedimentary rocks, some very highly weathered igneous or metamorphic rocks, boulder-clays.
Weak rock.	1.25 – 5.0.	
Moderately weak rock	5.0 – 12.5	
Moderately strong rock	12.5 – 50.0	Some sedimentary rocks, some foliated metamorphic rocks, highly weathered igneous and metamorphic rocks.
Strong rock.	50 – 100	Some low-grade metamorphic rocks, marbles, some strongly cemented sandstones (silica cement), some weathered and metamorphic igneous rocks.
Very strong rock.	100 – 200	Mainly plutonic, hypabyssal and extrusive igneous rocks (medium to coarse grained), sedimentary quartzites, strong slate, gneisses.
Extremely strong rock.	> 200	Fine-grained igneous rock, metamorphic quartzites, some hornfelses.